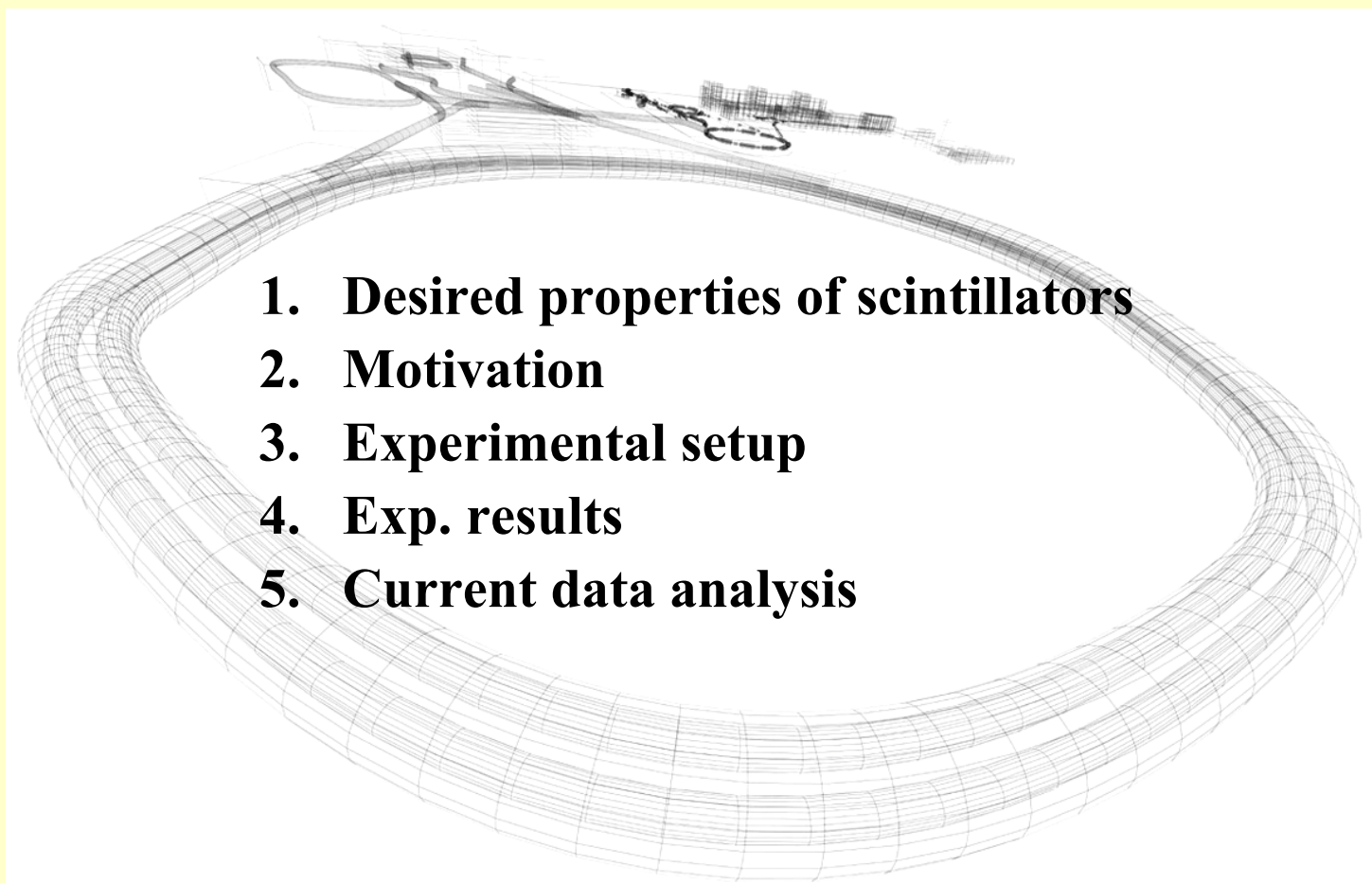


# Scintillation screen investigations for high current ion beams

**Eiko Gütlich<sup>1,2</sup>, Peter Forck<sup>1</sup>, Wolfgang Ensinger<sup>2</sup>, Beata Walasek-Höhne<sup>1</sup>**

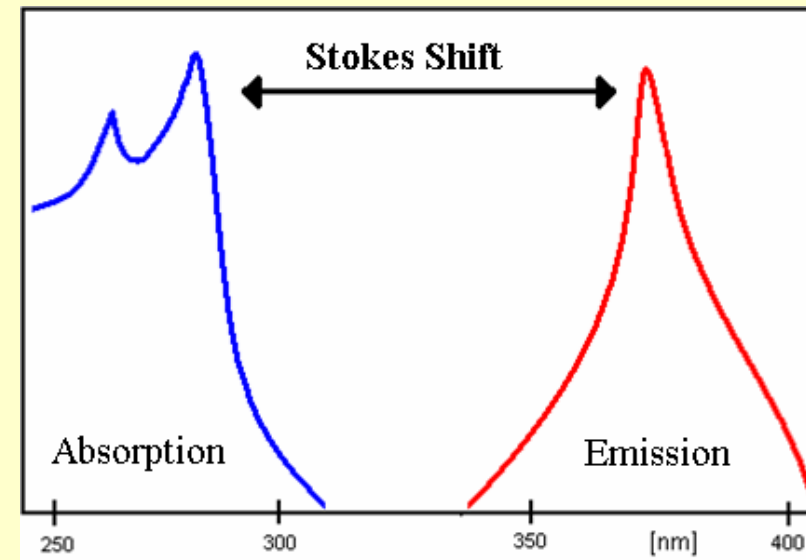
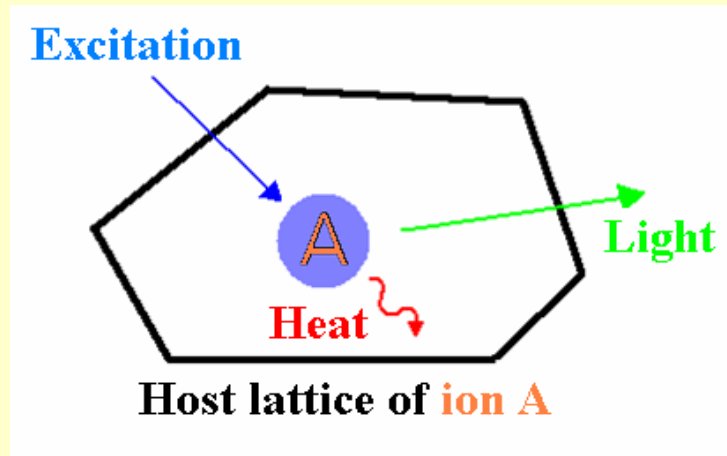
<sup>1</sup>GSI, Darmstadt, Germany    <sup>2</sup>Technical University Darmstadt, Germany



- 1. Desired properties of scintillators**
- 2. Motivation**
- 3. Experimental setup**
- 4. Exp. results**
- 5. Current data analysis**

# Desired properties of scintillators

- The kinetic energy of the ion is converted into light
- Conversion with good quantum efficiency
- Light yield directly proportional to number of particles
- Small absorption of induced light
- Small temperature dependency of scintillation



# Motivation

**Scintillator screens are widely used for qualitative measurements:**

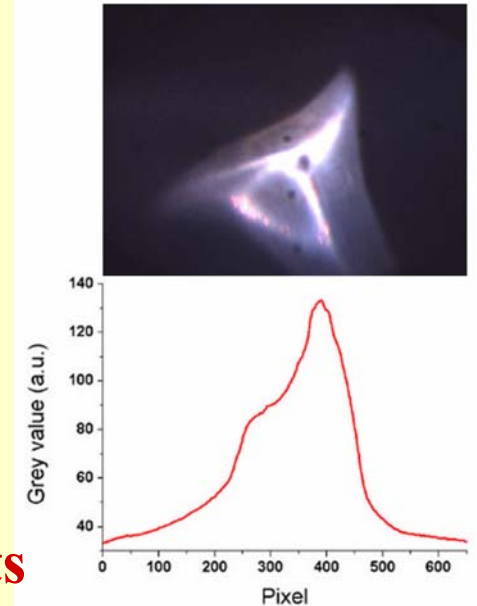
- simple profile measurements system
- complete 2-dimensional beam information (Profile Grid  $\rightarrow$  2x1D)
- used for beam alignment

**But we want to perform quantitative measurements**

**$\rightarrow$  Investigation for high currents :**

**( some mA, for up to 1 ms @ 11.4 MeV/u  $\rightarrow$  some 100 $\mu$ m range in matter)**

- spatial resolution and linearity
- ageing effects
- dynamical behaviour



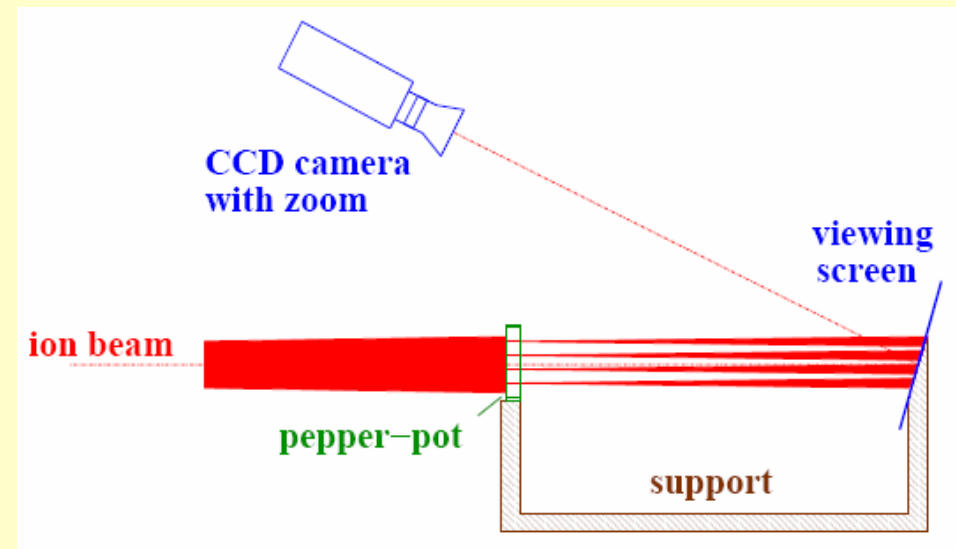
Courtesy of Jan Mäder (GSI)

# Possible application

## Single shot emittance measurement

### -Advantages of the Pepperpot method compared to the Slit-grid method

- gain of complete transversal phase space information from one macro pulse
- much shorter measurement time at the UNILAC Pepperpot: ~1 min.  
Slit-Grid: ~30-60 min.
- can be used for machines with low repetition rate



# Scintillators / Ion beams

**Desired property:** high light output

→ Single crystals: YAG:Ce, BGO,  $\text{CdWO}_4$ ,  $\text{CaF}_2\text{:Eu}$

Quartz glass: Quartz:Ce

**Expectation:** strong degradation effects for high current ion beams

**Desired property:** high resistance against high current ion beams

→ Ceramics:  $\text{ZrO}_2$ ,  $\text{ZrO}_2\text{:Mg}$ ,  $\text{Al}_2\text{O}_3$ ,  $\text{Al}_2\text{O}_3\text{:Cr}$ , BN

Quartz glass: Herasil

**Expectation:** low sensitivity

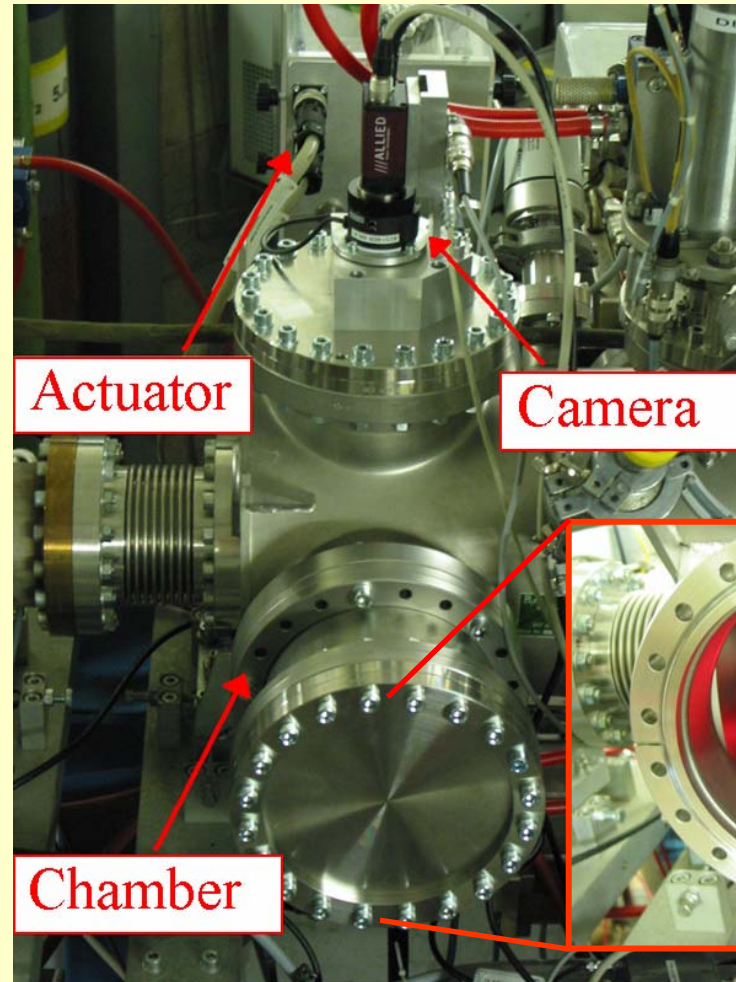
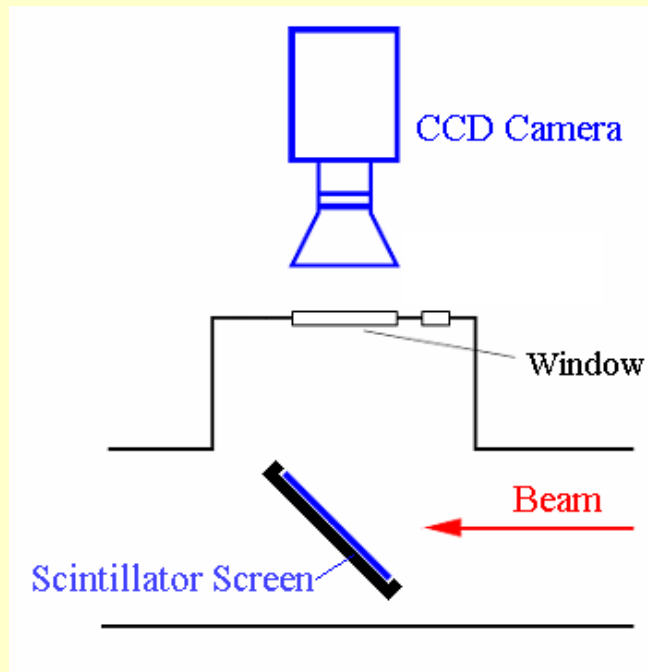
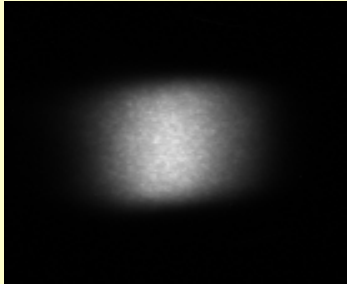
Investigated with  $\text{H}^+$ ,  $\text{C}^{2+}$ ,  $\text{Ar}^{10+}$ ,  $\text{Ni}^{9+}$ ,  $\text{Ta}^{24+}$  and  $\text{U}^{28+}$  Ions with energies between 4.8 and 11.4 MeV/u and beam currents from some nA to some mA.



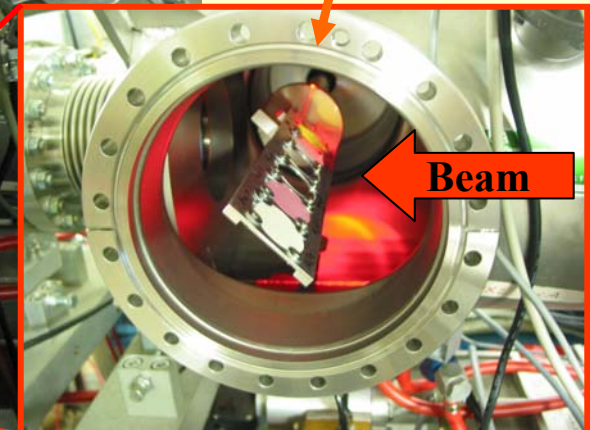
# Experimental setup

Image

10mm



Flange diameter  
200 mm



# Target holder / Camera

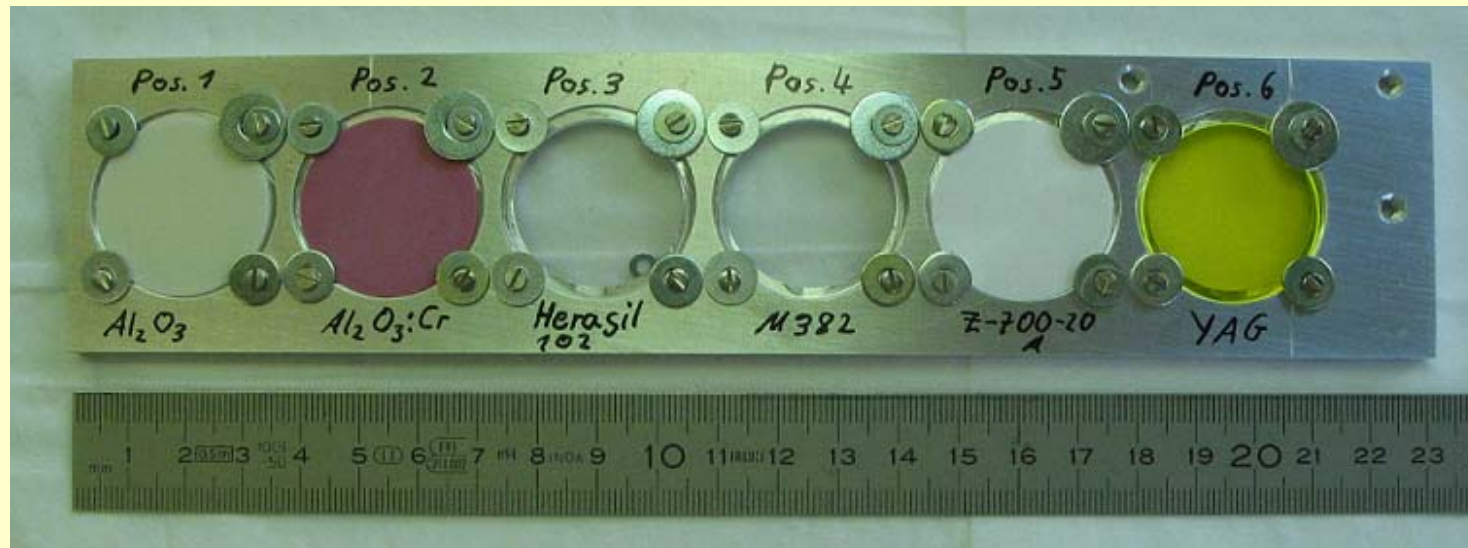
## Holder allows to:

- investigate 6 scintillator materials
- in one machine run
- at the same position → constant beam conditions

**Camera:** AVT Marlin  
VGA resolution  
8Bit monochromic

**Lens system:** Pentax 25mm

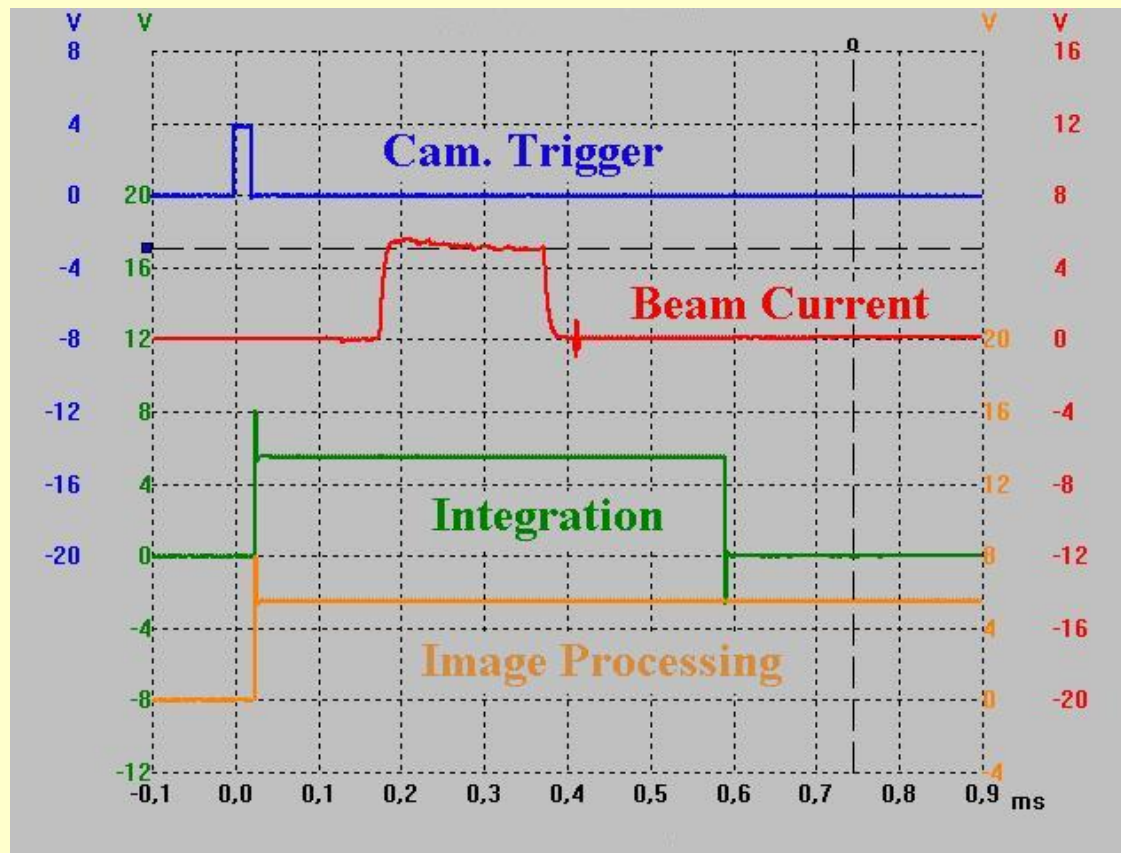
**Spatial resolution:** 10 Px/mm



Screen dimensions: Ø30mm x 1mm

# Camera timing

## Camera timing for pulsed ion beam



### Timing allows:

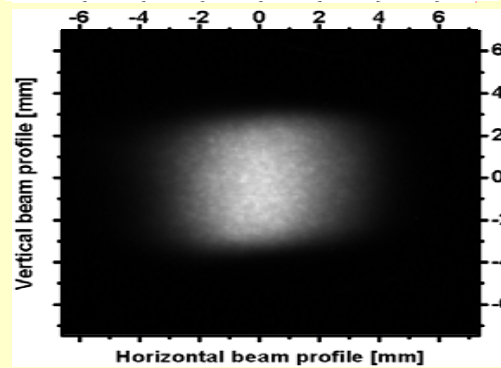
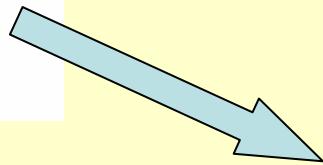
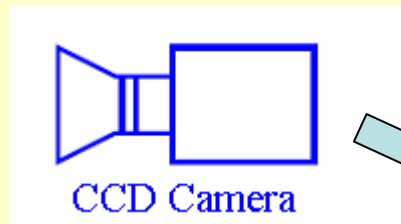
- to observe complete beam pulse
- measurements of afterglow
- max. 15 Frames /s

### Typical beam delivery:

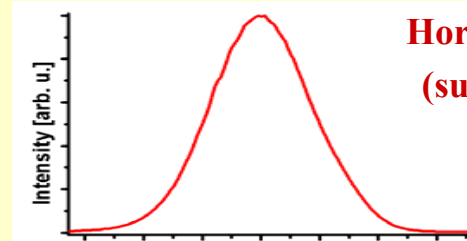
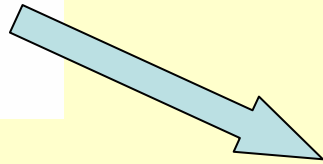
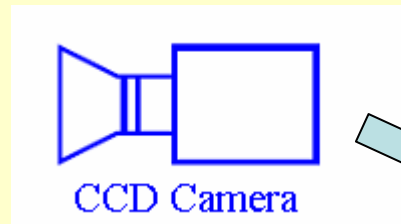
- pulse length 100  $\mu$ s
- repetition 10 per second



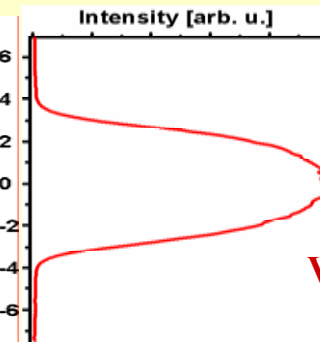
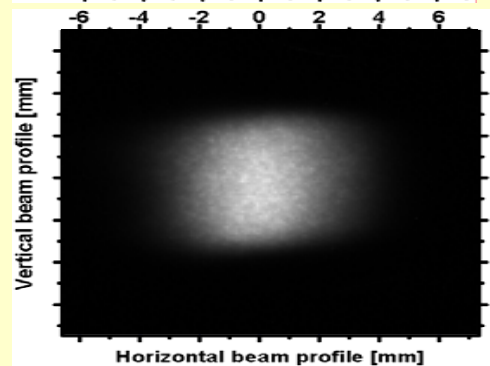
# Observed image parameters



# Observed image parameters

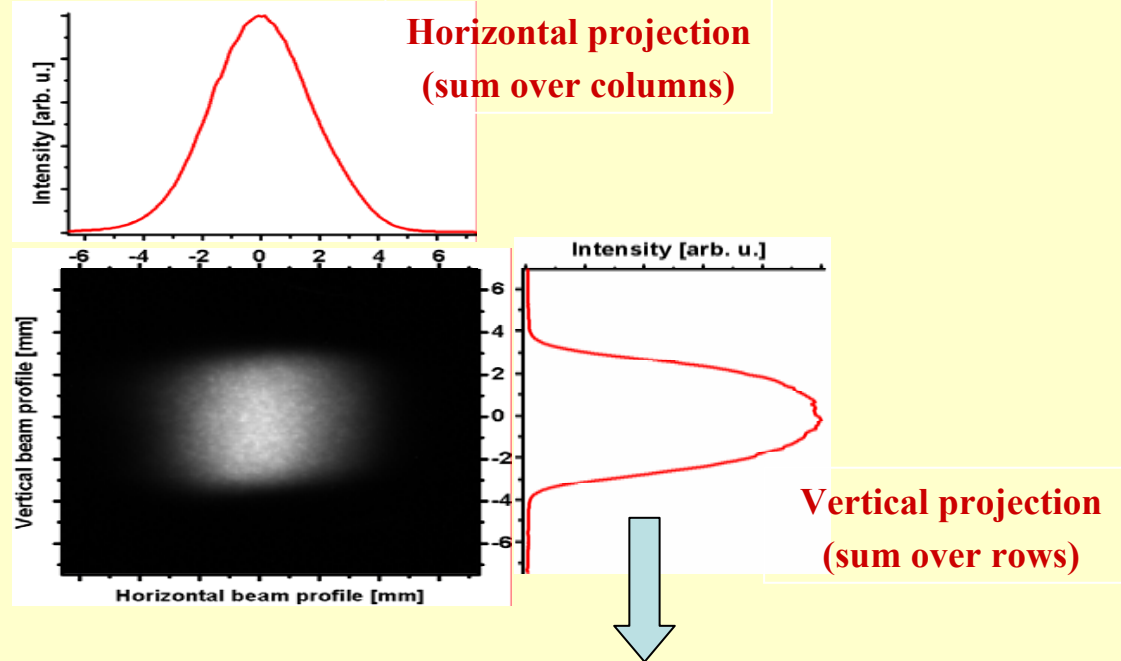
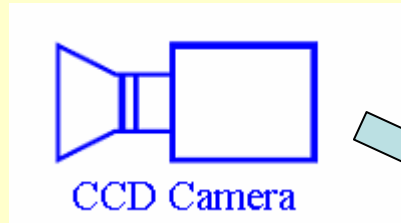


**Horizontal projection**  
(sum over columns)



**Vertical projection**  
(sum over rows)

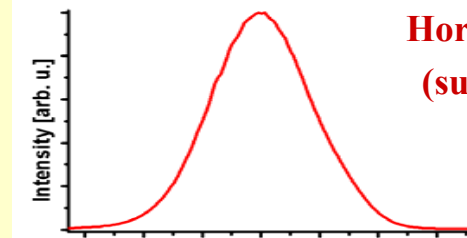
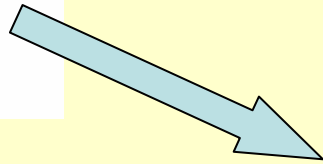
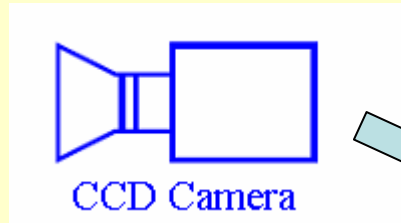
# Observed image parameters



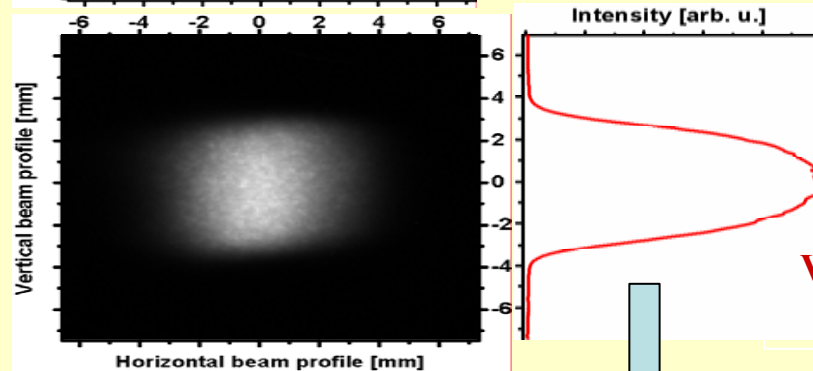
## From the projection:

- Light yield (integral)
- Center of projections ( $\mu$ , 1<sup>st</sup> moment)
- Beam width ( $\sigma$ , 2<sup>nd</sup> moment)
- Skewness (prop. to 3<sup>rd</sup> moment)
- Kurtosis (prop. to 4<sup>th</sup> moment)

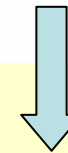
# Observed image parameters



Horizontal projection  
(sum over columns)

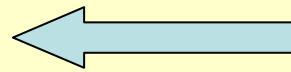


Vertical projection  
(sum over rows)

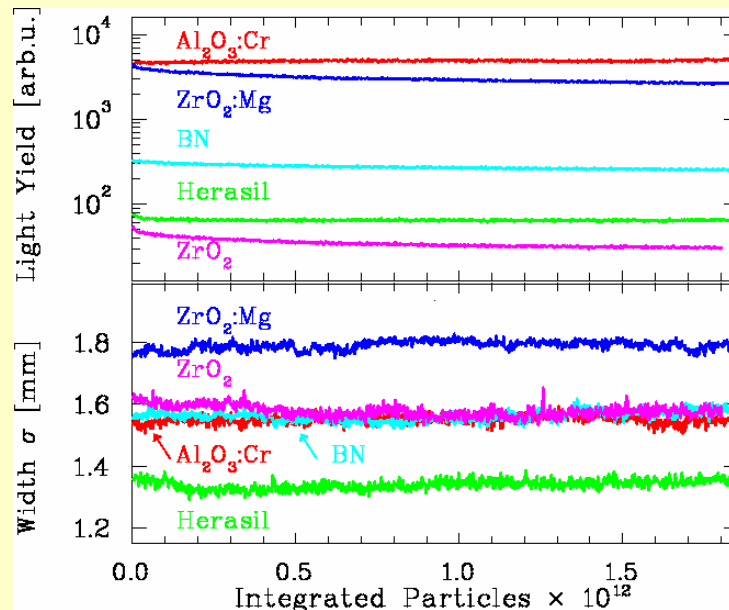


## From the projection:

- Light yield (integral)
- Center of projections ( $\mu$ , 1<sup>st</sup> moment)
- Beam width ( $\sigma$ , 2<sup>nd</sup> moment)
- Skewness (prop. to 3<sup>rd</sup> moment)
- Kurtosis (prop. to 4<sup>th</sup> moment)

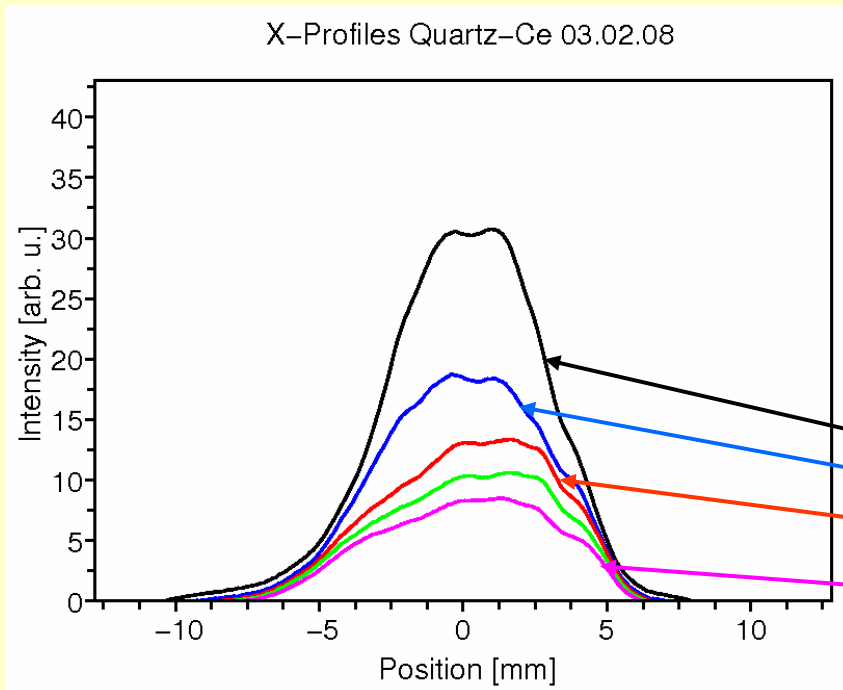


## Comparison of Materials



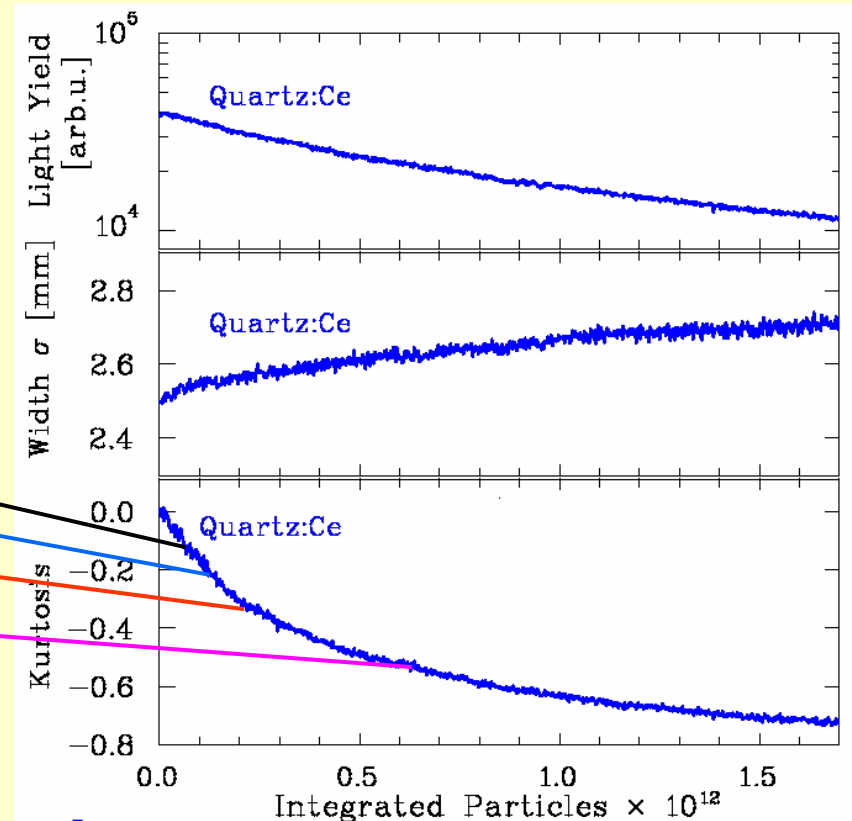


# Example for degradation effect



→ Strong profile deformation

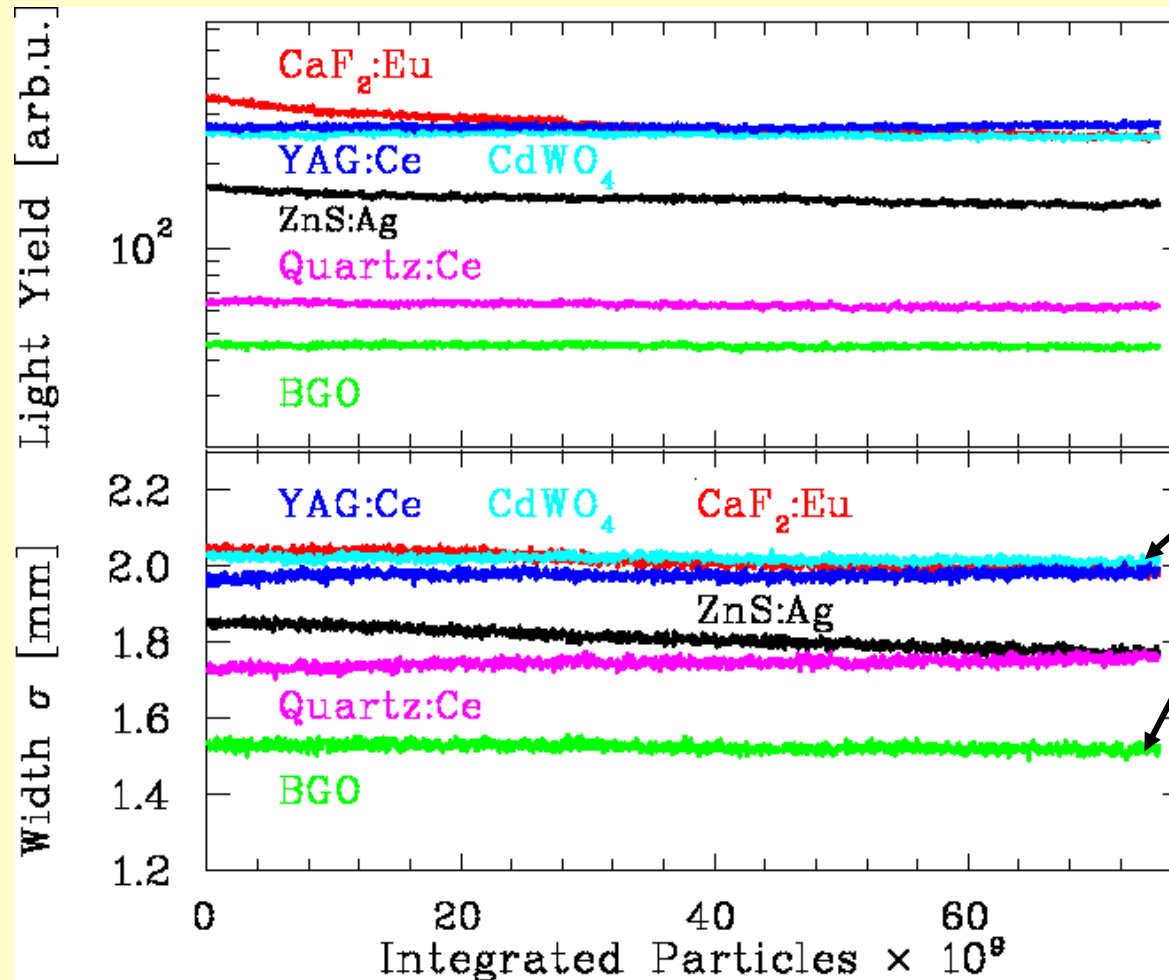
Beam parameters:  $^{40}\text{Ar}^{10+}$ ,  $2 \cdot 10^9$   
Ions/Pulse in  $100\mu\text{s}$ ,  $\sim 30\mu\text{A}$ , 1Hz



## Results:

- not only the beam width is important
- characterization by first 4 moments

# Behaviour of standard scintillators



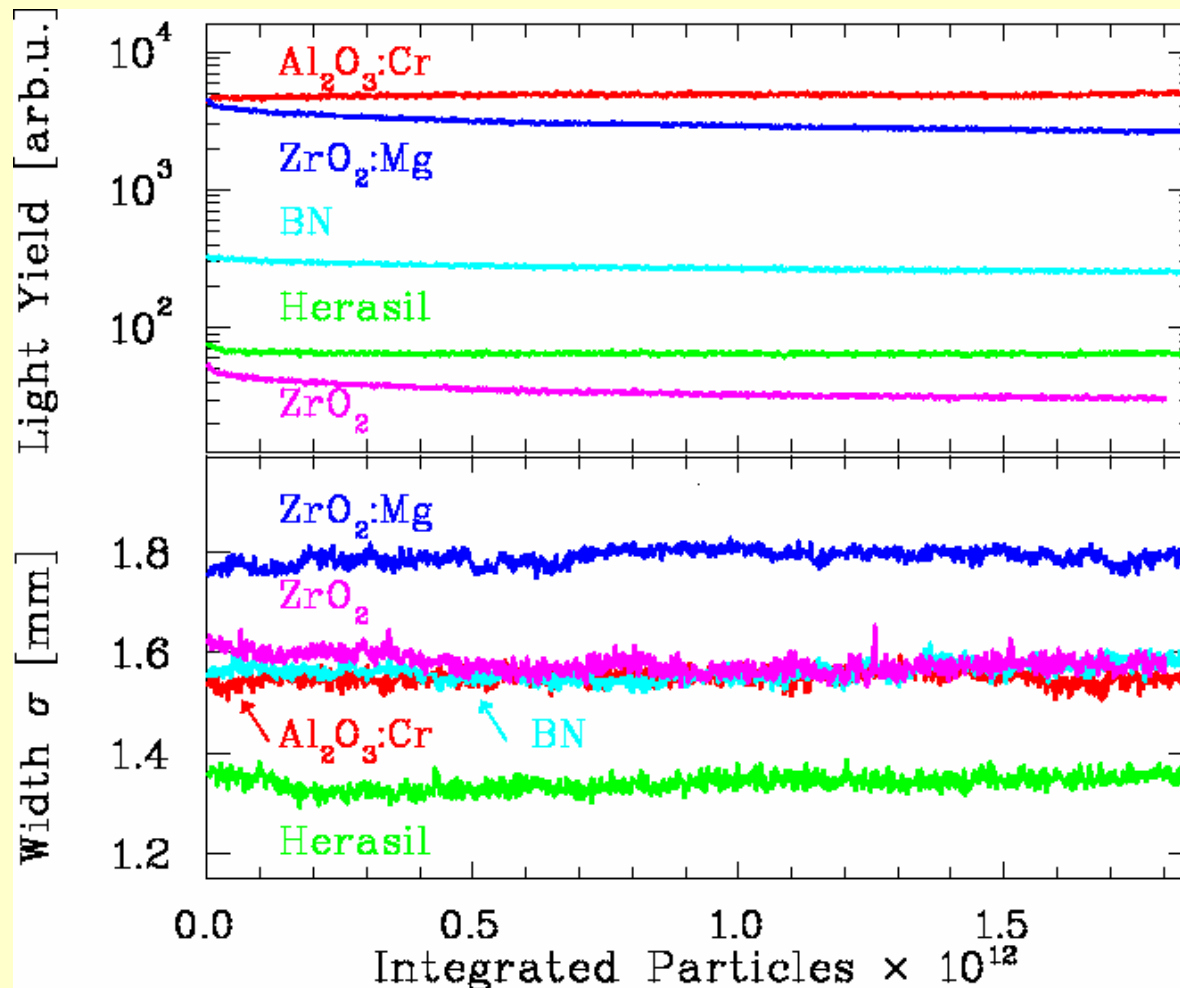
## Result:

- even for purpose built scintillators different width reading of 25%
- not suitable for higher currents

Average temperature: 23°C  
(backside of  $\text{ZnS:Ag}$ )

Beam parameters:  $^{12}\text{C}^{2+}$ ,  $5 \cdot 10^6$  Ions/Pulse in 100 $\mu\text{s}$ ,  $\sim 17\text{nA}$ , 12.6Hz, 15000 beam pulses

# Light yield and profile width @ low intensity



## Results:

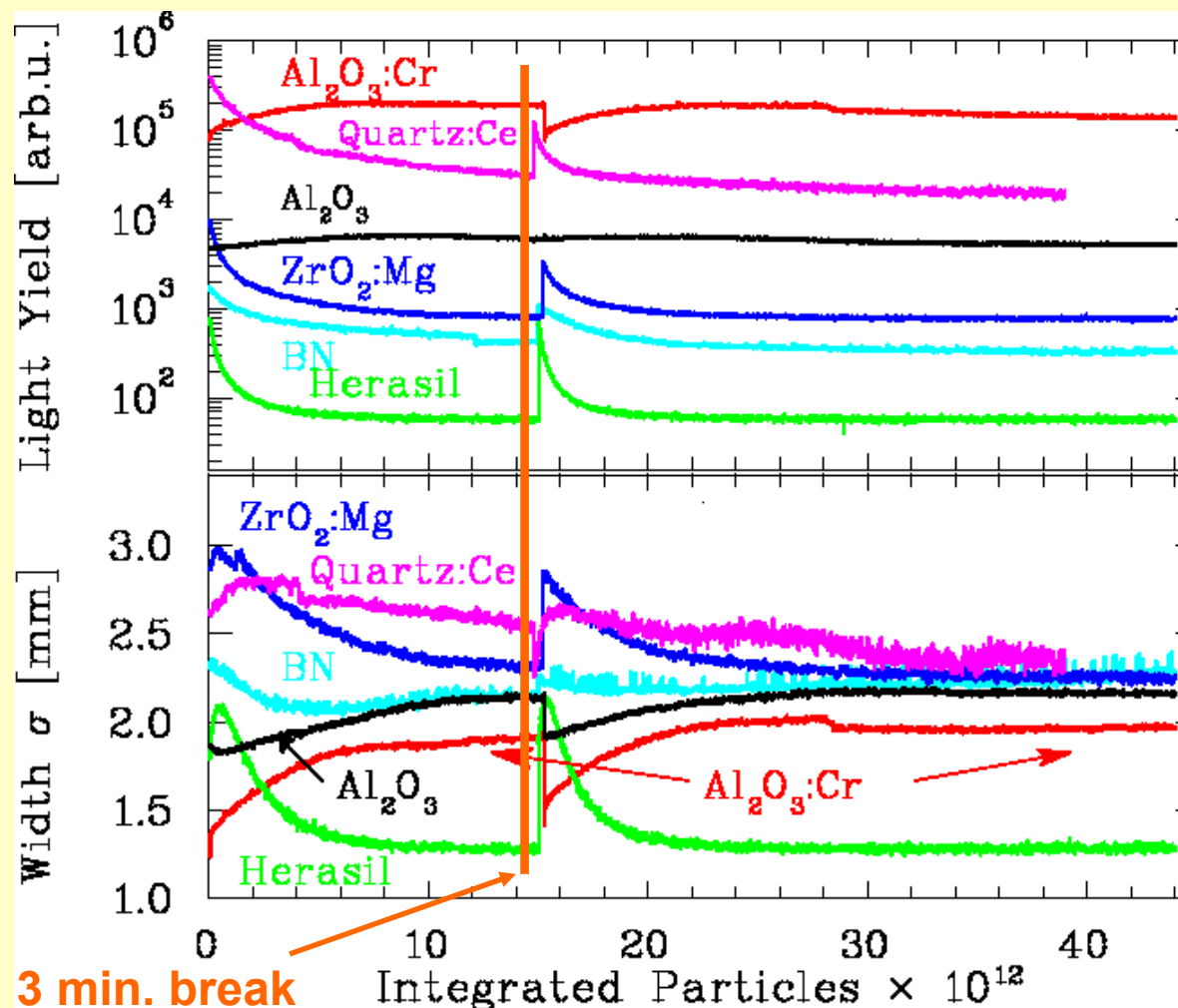
- reproducible behavior
- different light yield and width reading
- light yield does not correlate with beam width
- different beam shape (from higher stat. moments)

Difference of 14% in profile width is not negligible for quantitative evaluation

Average temperature:  $\sim 47^\circ\text{C}$   
(backside of  $\text{ZrO}_2:\text{Mg}$ )

Beam parameters:  $^{40}\text{Ar}^{10+}$ ,  $2 \times 10^9$  Ions/Pulse in  $100\mu\text{s}$ ,  $\sim 30\mu\text{A}$ , 1Hz, 1000 beam pulses

# Light yield and profile width @ higher intensity



**10 times higher beam current**

## Results:

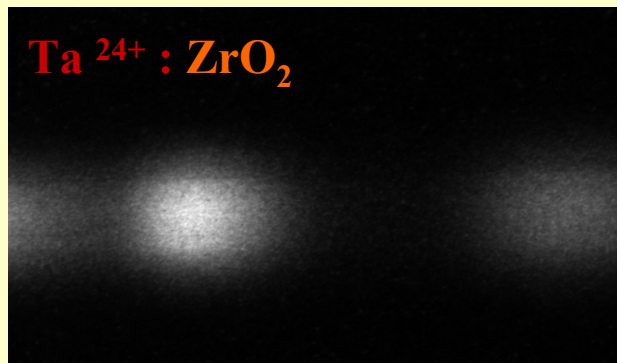
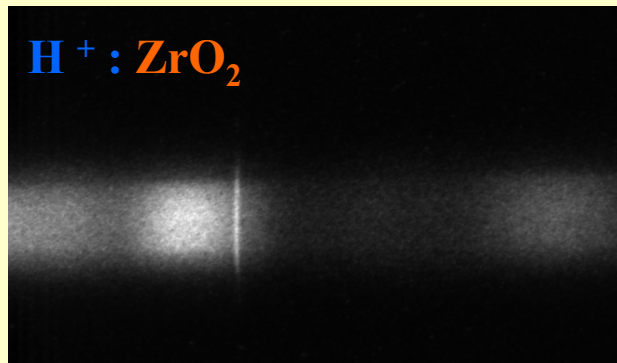
- light yield and profile width depend on material
- different dynamical behaviour
- possible reasons: surface modification and temperature dependency

Average temperature:  $\sim 240^\circ\text{C}$   
(backside of  $\text{ZrO}_2:\text{Mg}$ )

**Beam parameters:**  $^{40}\text{Ar}^{10+}$ ,  $2 \cdot 10^{10}$  Ions/Pulse in  $100\mu\text{s}$ ,  $\sim 0.3\text{mA}$ ,  $2.6\text{Hz}$ , 2200 beam pulses



# Spectra of the scintillators @ medium current



Wavelength [nm]

—  $Ta^{24+}$

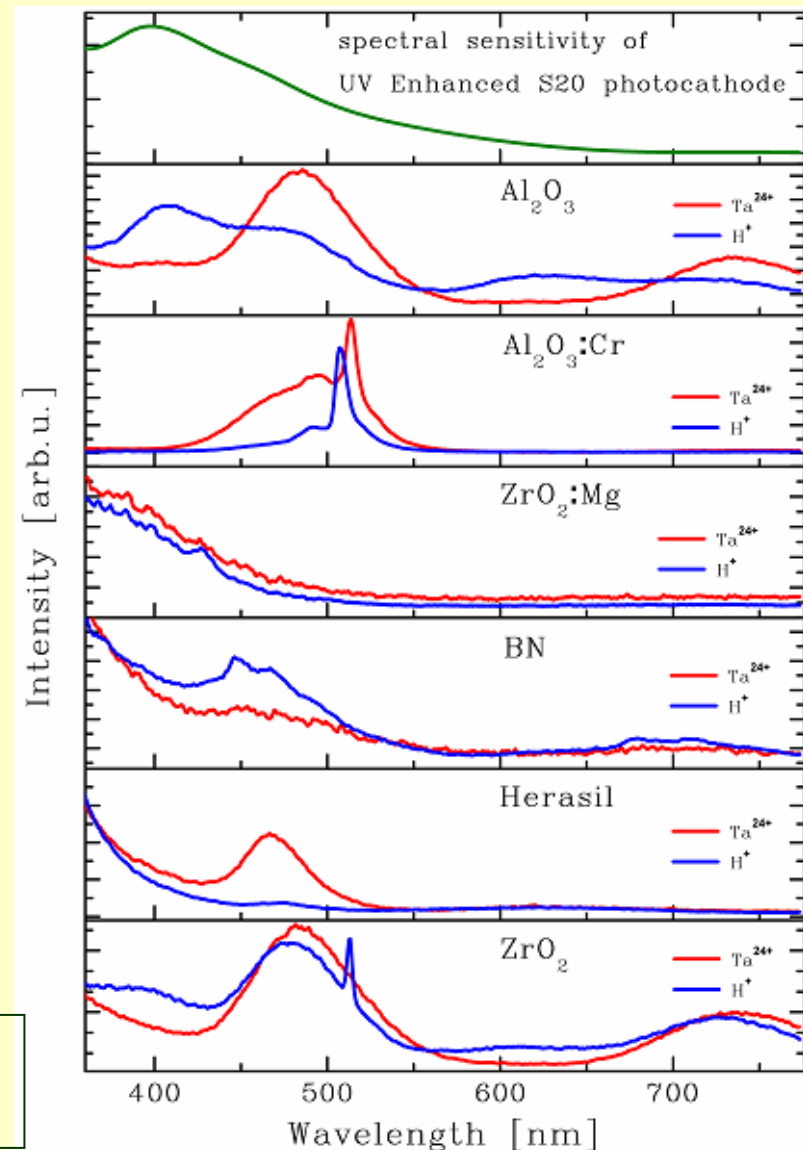
—  $H^+$

## Result:

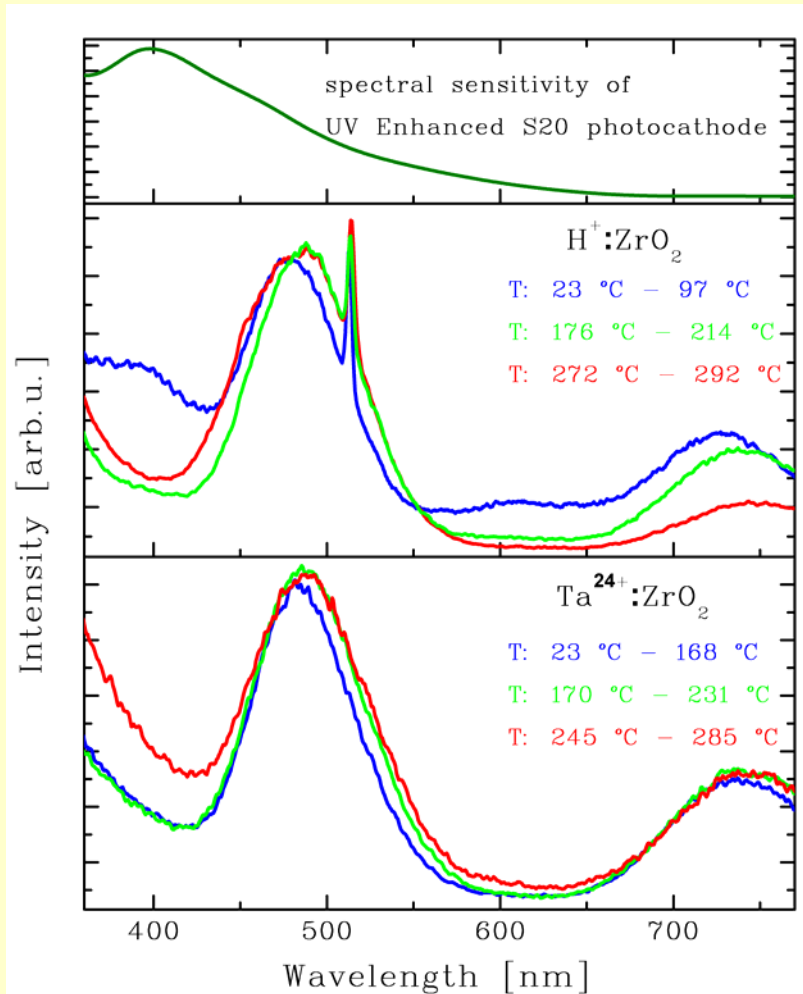
- spectra depend on the ion species → investigation

Beam parameters:  $H^+$ ,  $4.1 \cdot 10^{11}$  Ions/Pulse in 2ms,  $\sim 32.8 \mu A$ , 2Hz

$Ta^{24+}$ ,  $8.8 \cdot 10^9$  Ions/Pulse in 100 $\mu s$ ,  $\sim 0.35 mA$ , 1Hz

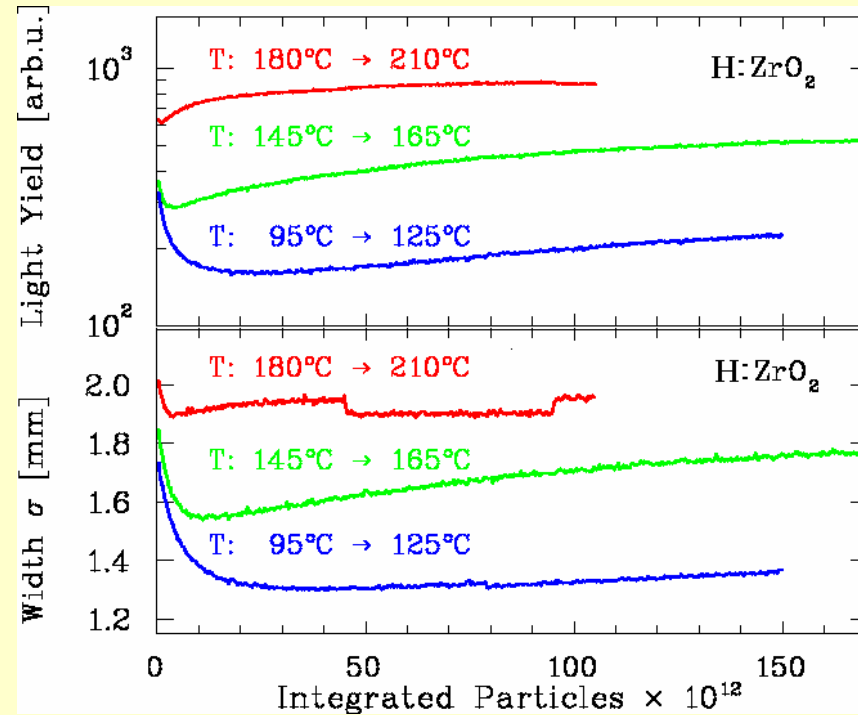


# Temperature dependence – medium current



**Beam parameters:**  $\text{H}^+$ ,  $4.1 \cdot 10^{11}$  Ions/Pulse in 2ms,  $\sim 32.8 \mu\text{A}$ , 2Hz

$\text{Ta}^{24+}$ ,  $8.8 \cdot 10^9$  Ions/Pulse in 100 $\mu\text{s}$ ,  $\sim 0.35\text{mA}$ , 1Hz



## Results:

- Light yield, imaged beam width and spectrum depend on the temperature

# Status until summer '09

## What has been done:

- Quantitative investigations on different materials
- Materials show different, but reproducible behaviour
- **Profile width depends on scintillator material and the screens temperature!**
- **Spectrum of the screen could depend on the ion species and the temperature!**
- **Light yield AND profile width depend on ion dose!**

**ZrO<sub>2</sub>, ZrO<sub>2</sub>:Mg and undoped Quartz glass show promising results**

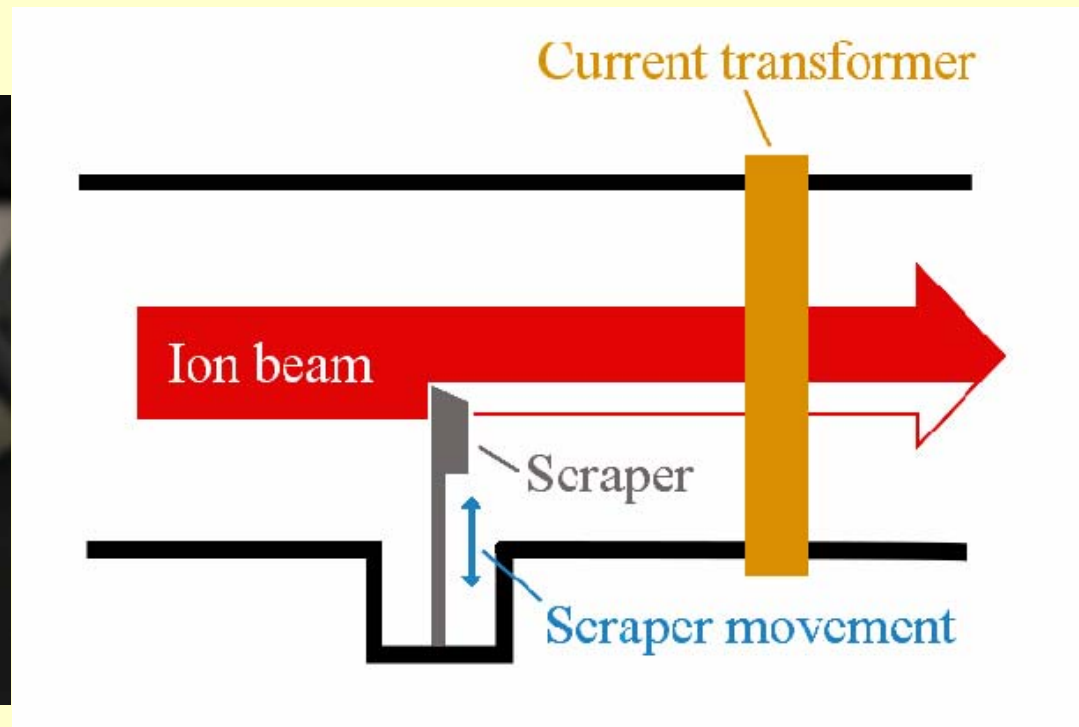
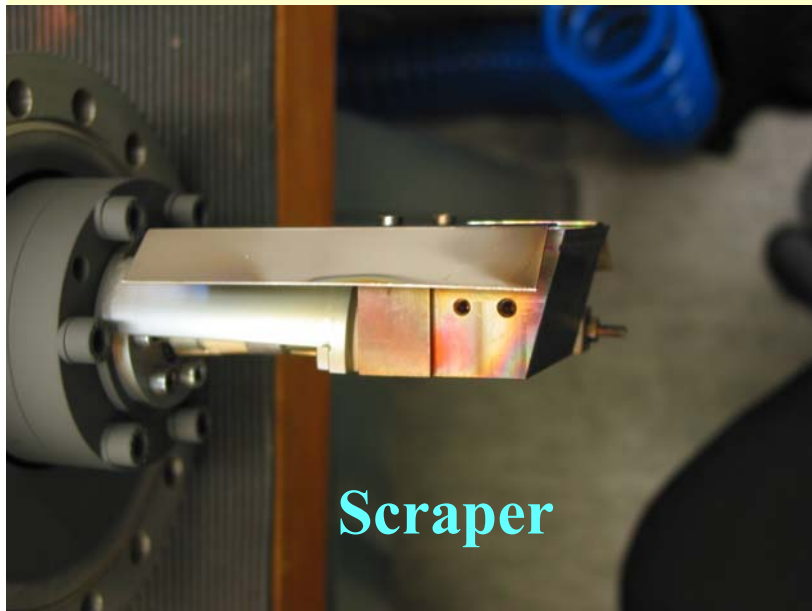
## The next steps:

- design of a new data acquisition system
- develop new experiment to determine the "real" beam profil

# Question

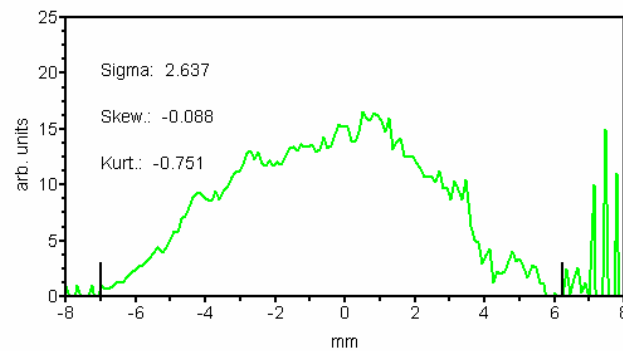
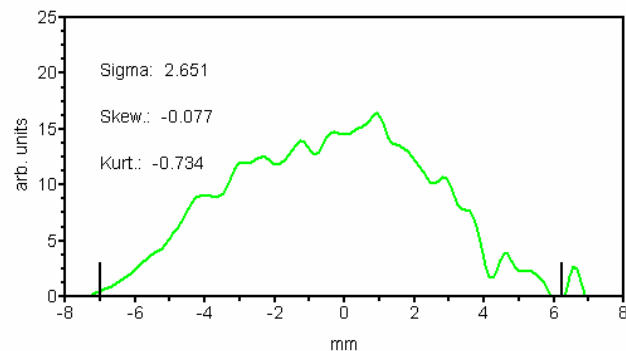
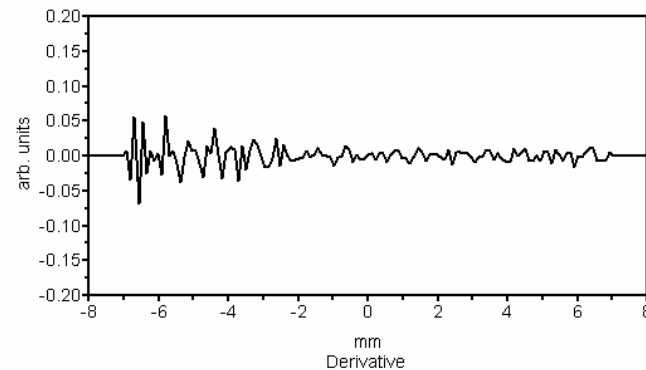
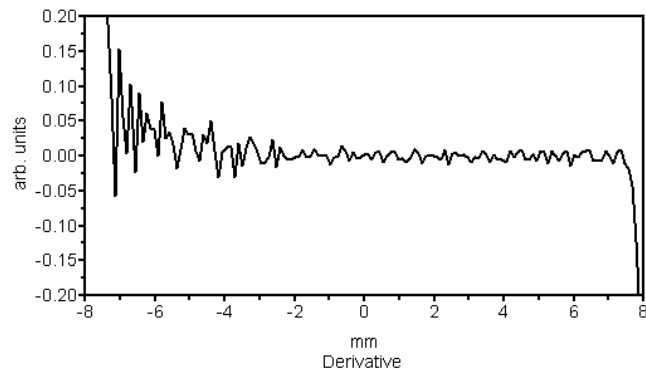
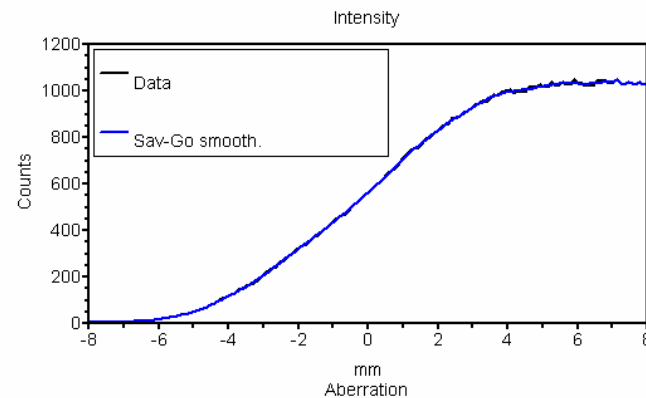
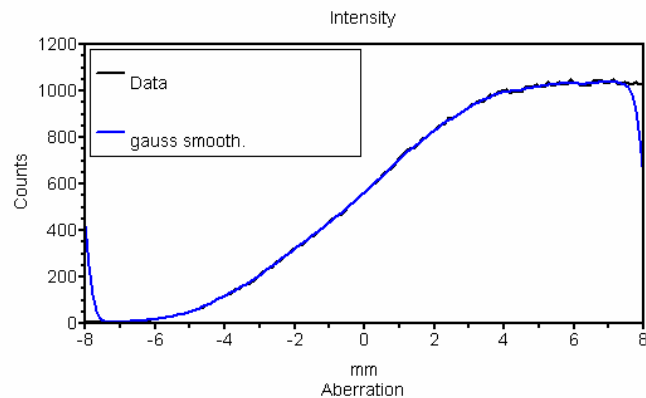
- How can one obtain a trusted beam profile
- What does the "real" ion beam look like

One can try to obtain a horizontal beam profile by using a scraper





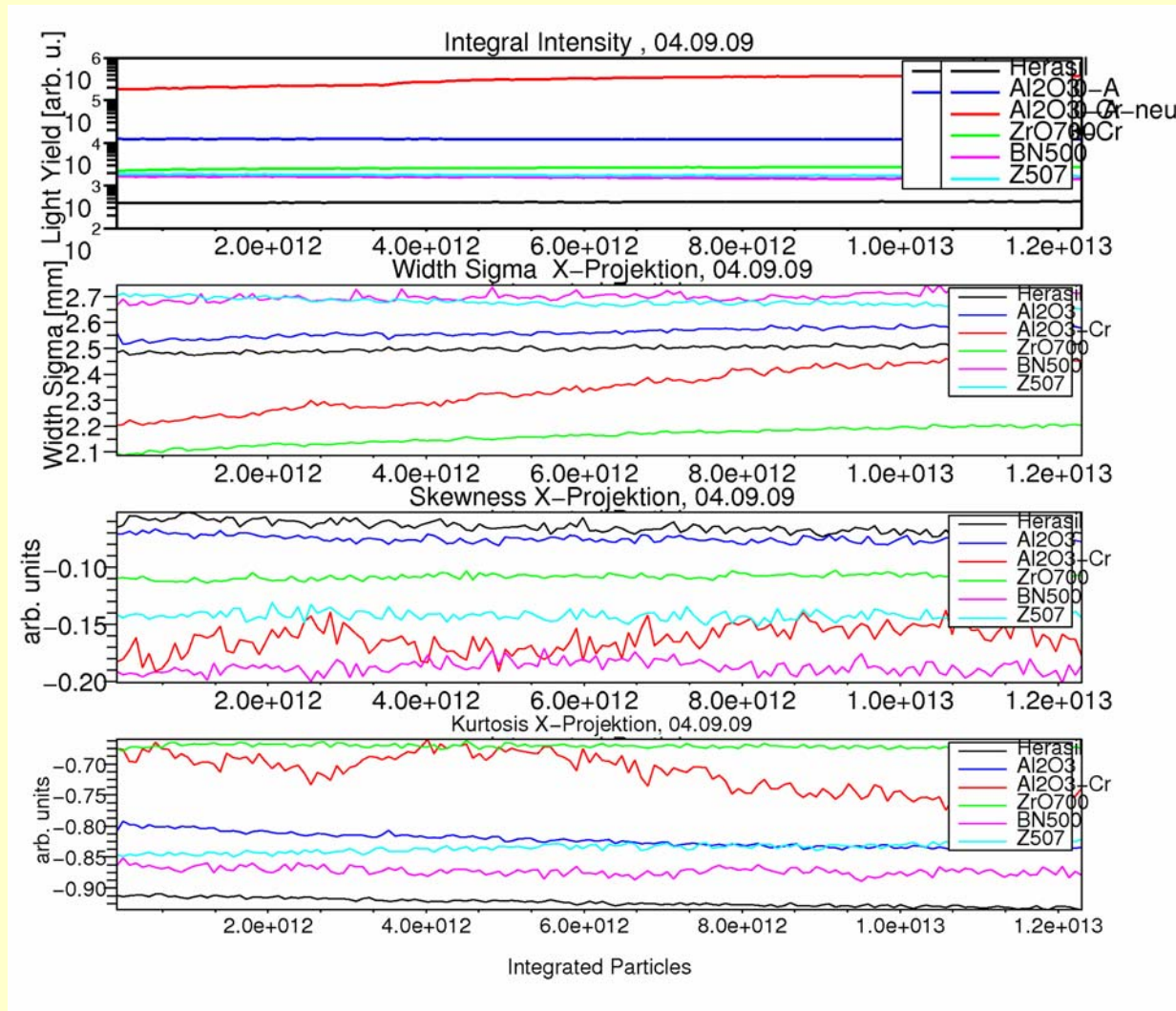
# Current data analysis



## Results:

- One can obtain a beam profile with a scraper
- The fitting is a critical issue

# Current data analysis



## Profile values (scraper):

**Sigma** = 2.64

**Skewness** = -0.088

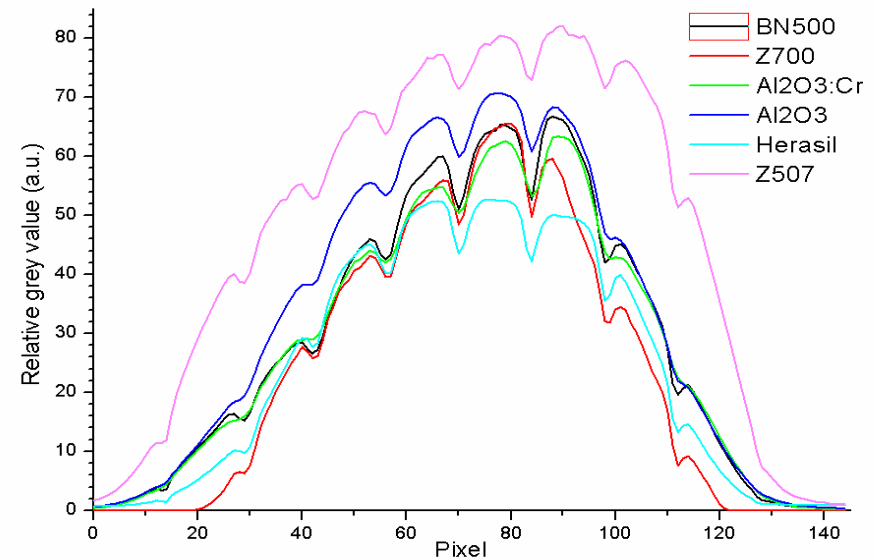
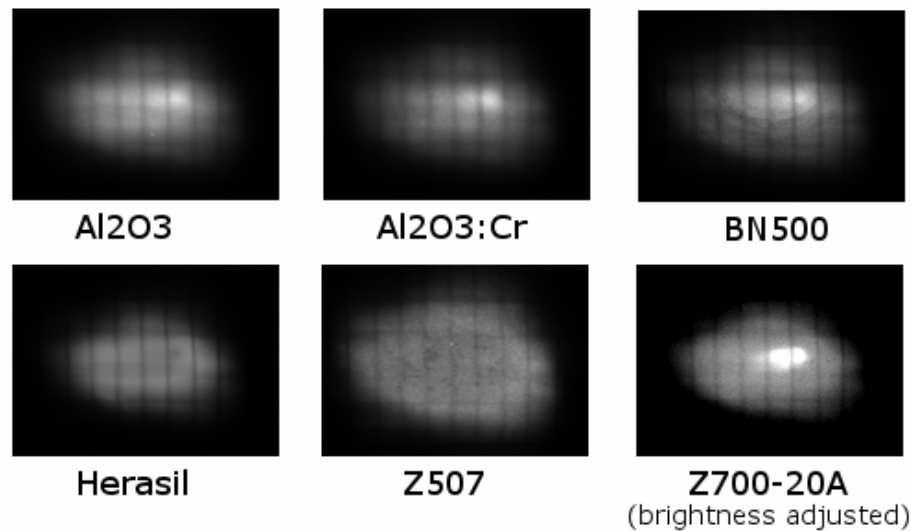
**Kurtosis** = -0.751

→ Al<sub>2</sub>O<sub>3</sub> shows the best agreement with the scraper-values

## Results:

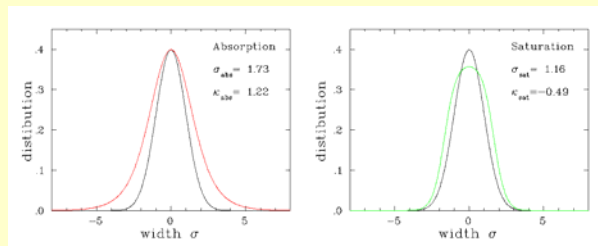
- Obtained values for sigma, skewness and kurtosis agree with the results from the screens

# Current data analysis



## Results:

- As well as the light transport in the material and the linearity contribute to the signal.
- Linearity seems to dominate (28% difference in sigma)
- First ansatz → convolution



# Summary

## Data analysis showed:

- One can obtain a beam profile with a scraper
- Obtained values for sigma, skewness and kurtosis agree with the results from the screens
- Light transport in the sample can not explain the difference in beam width

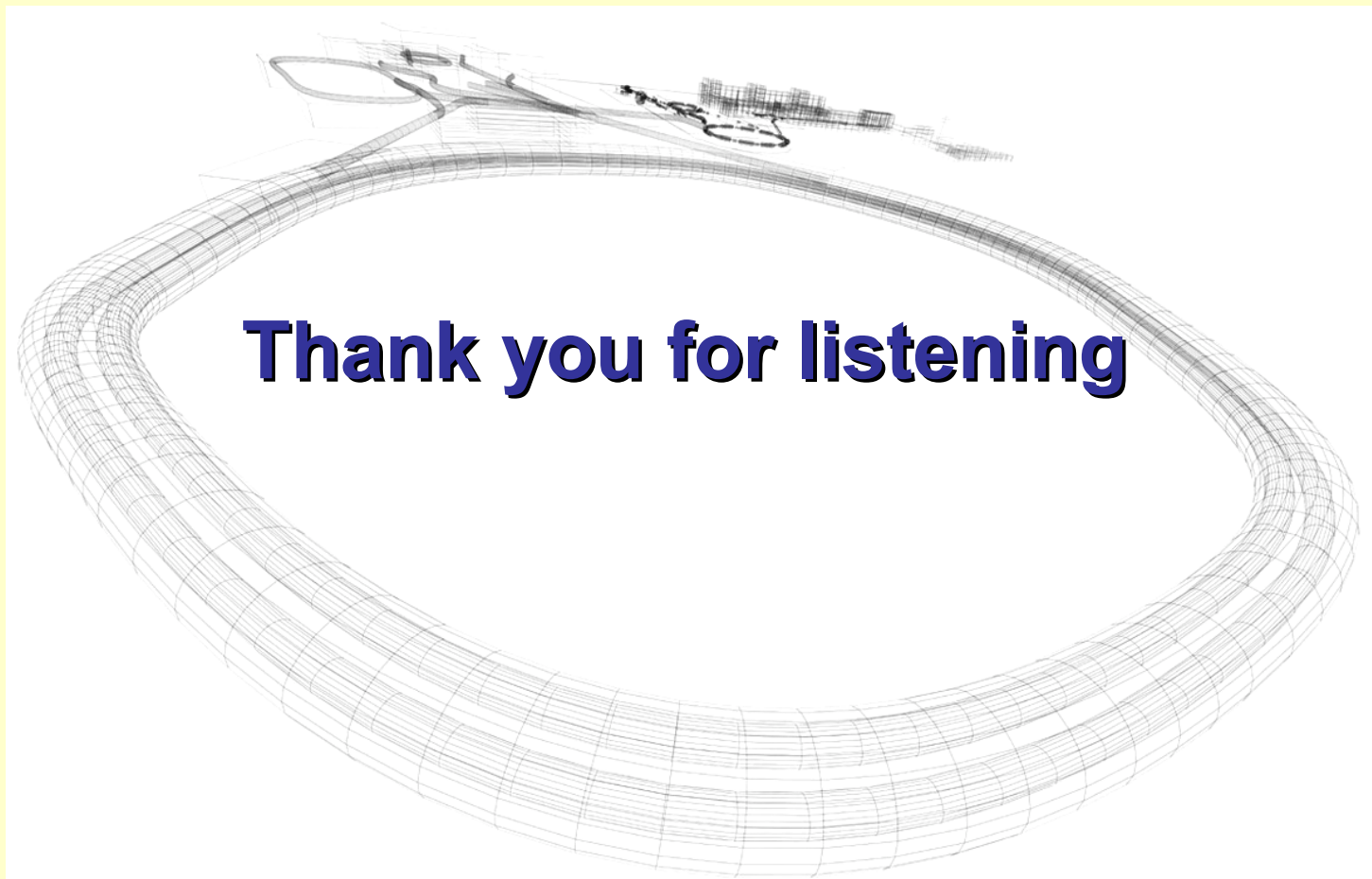
## The next steps:

- investigate the influence of the grain size and surface roughness
- analysis of the thermal effects, surface modifications
- further spectroscopic investigations
- approach for a theoretical description of the observed effects
- long-term objective: scintillator for pepperpot-device

⇒ improving knowledge of scintillation process

**Thank you  
for listening**





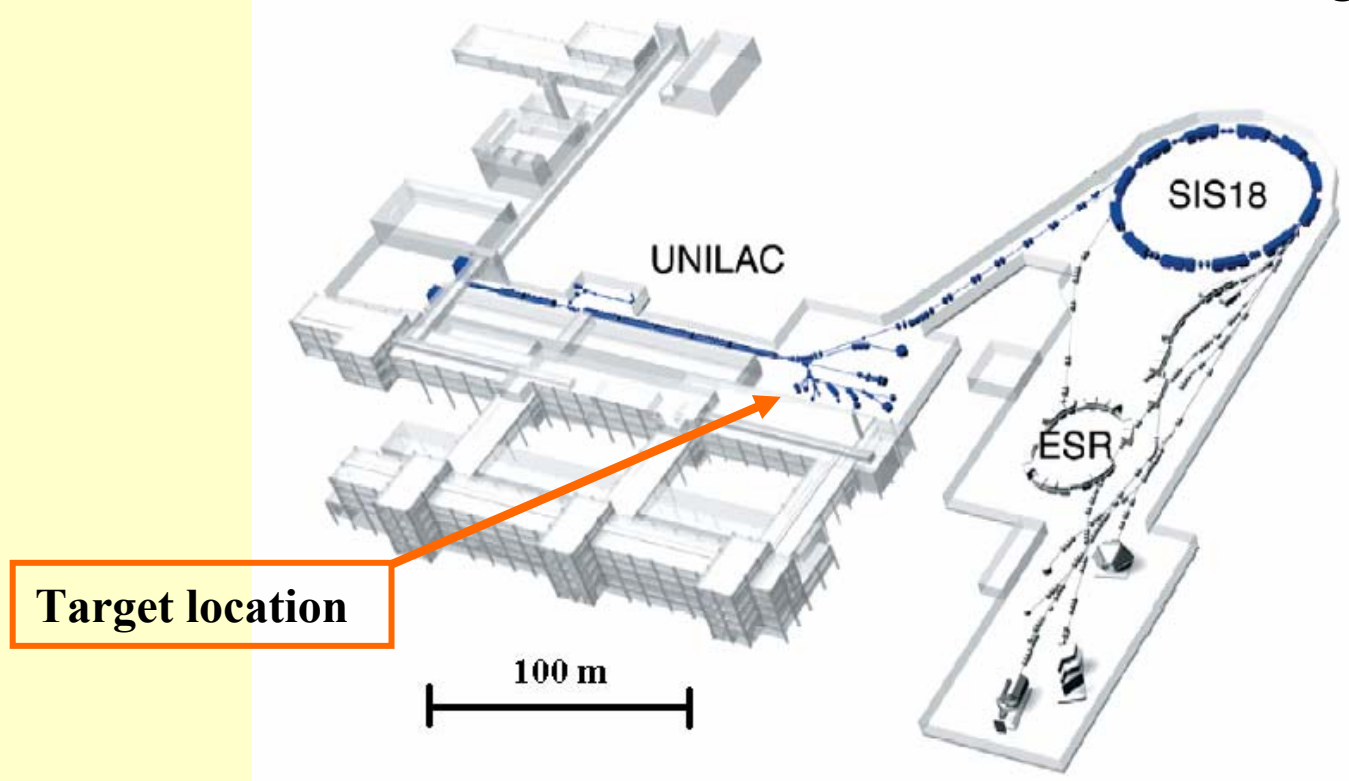
# GSI Facility

## Linac UNILAC:

- all ions from protons to Uranium
- pulsed currents up to 10 mA
- energies up to 15 MeV/u

## Synchrotron SIS18:

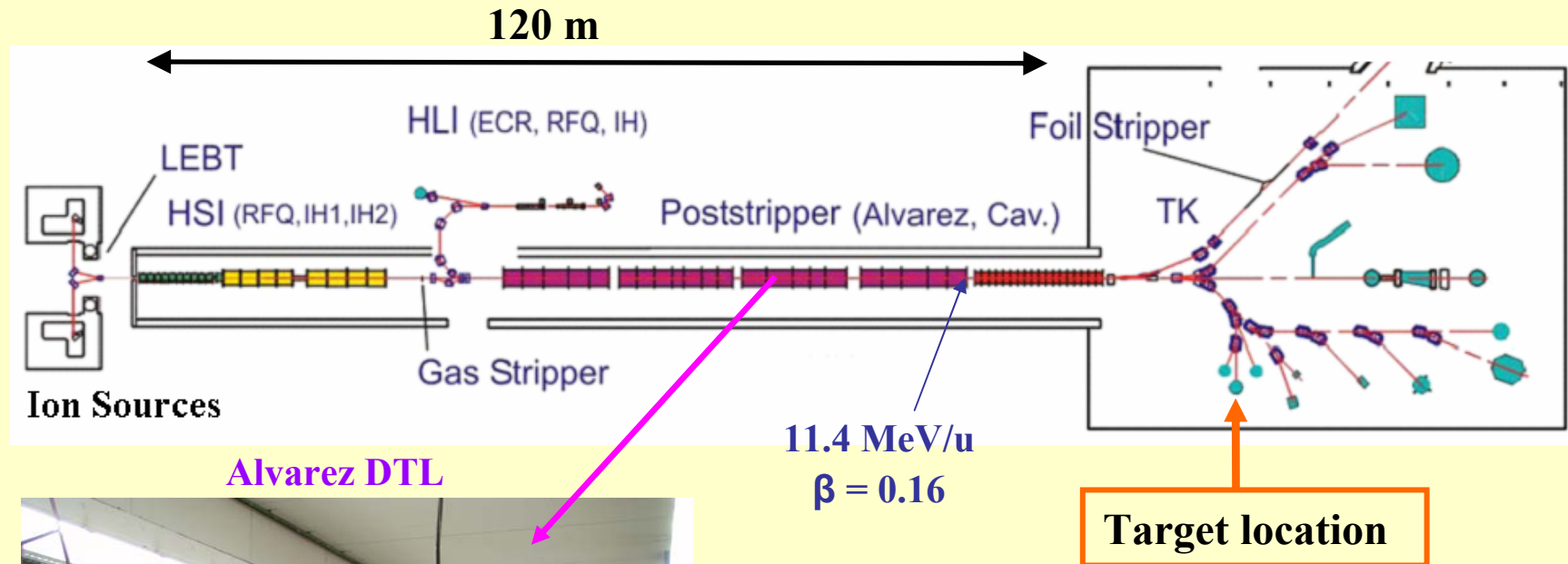
- ions from protons to Uranium
- up to  $10^{11}$  stored particles
- energies up to 4 GeV/u



## Future extension:

GSI will be the injector for **FAIR: Facility for Antiproton and Ion Research**, with high beam currents in the UNILAC

# The GSI LINAC



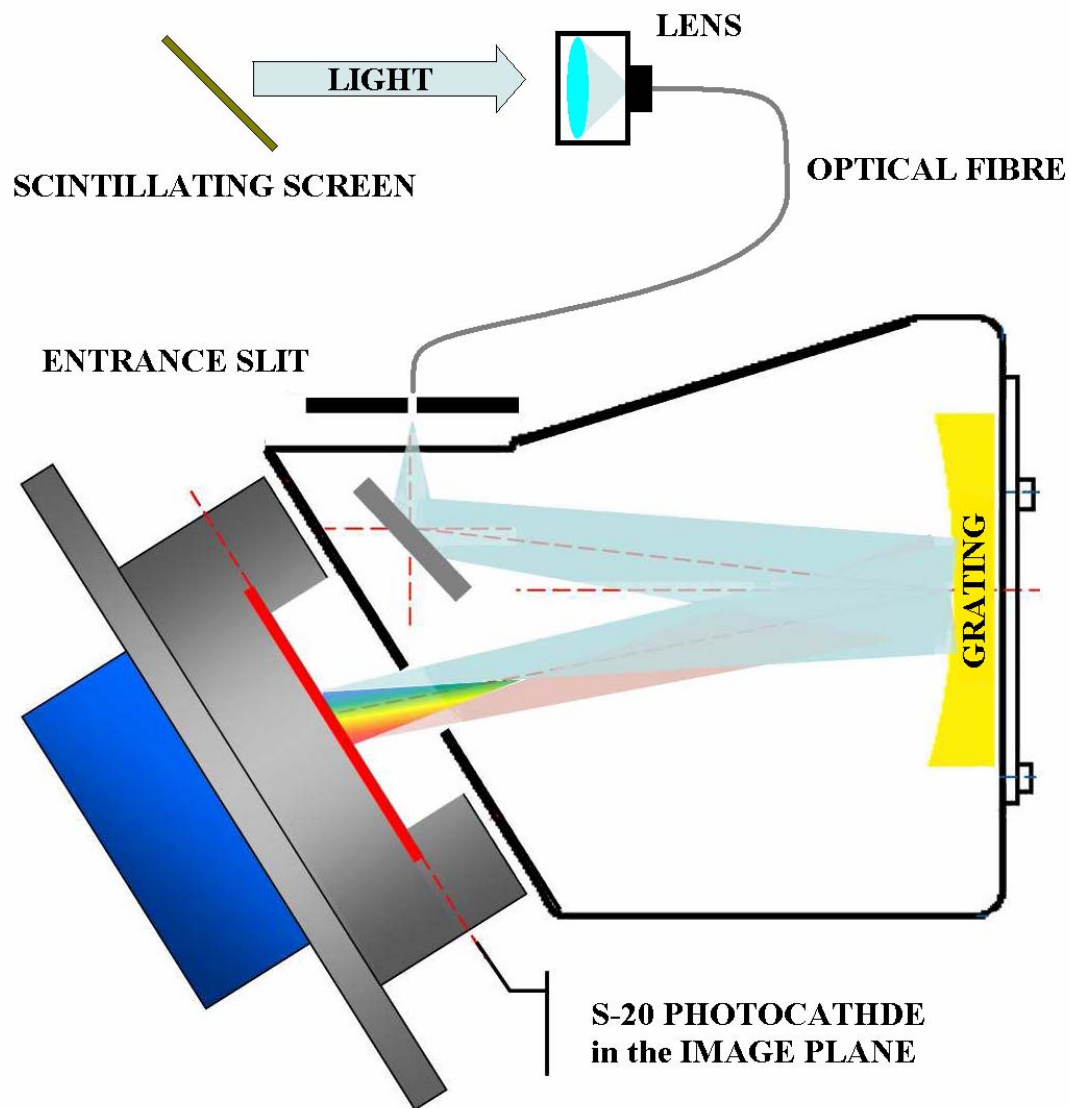
## UNILAC:

- built in the 70's but continually upgraded
- will be used as an injector for FAIR

## Typical beam parameters:

- 10 mA for 1 ms  $\rightarrow$  several 100 kW pulse power
- up to 50 Hz repetition rate

# Spectroscopic studies on scintillation screens



## Experimental setup:

### Spectrometer:

- HORIBA JOBIN YVON

CP 140-202

- wavelength range: 190-800 nm

average dispersion 50 nm/mm

focal length: 140 mm

### Intensified camera:

Photocathode: S20, UV Enhanced  
double MCP

Phosphor screen P46

fibre coupled to Basler 311f CCD  
Camera

### Ocean Optics fibre

400  $\mu\text{m}$





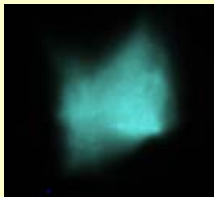
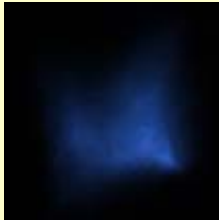
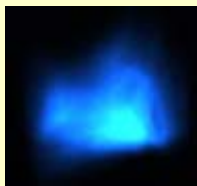

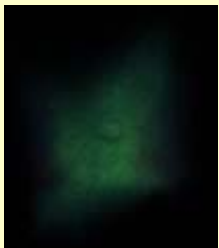


# Ion Beams

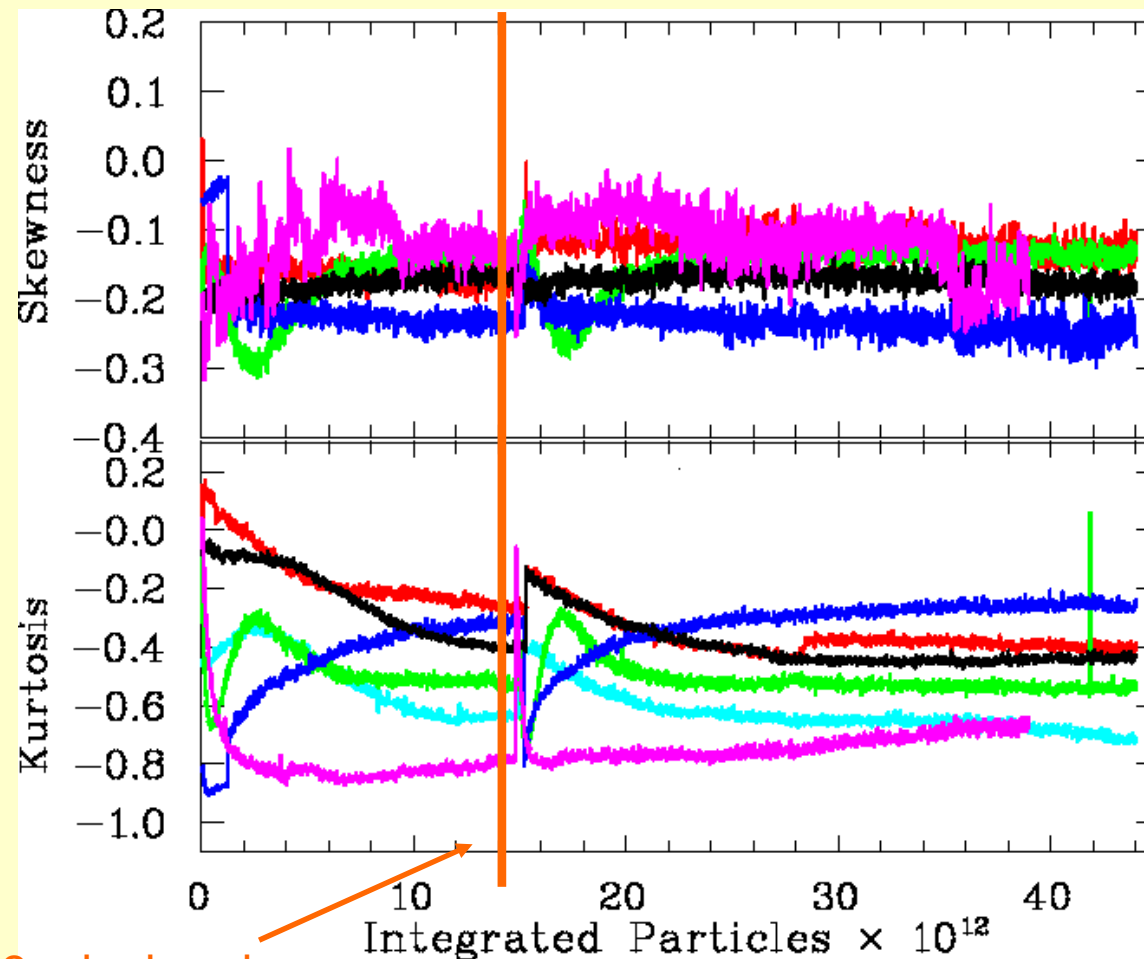
Ion	Energy [Mev/u]	Beam current	Pulse lenght	ppp	$P_{peak}$	$P_{aver}$
$^{12}C^{2+}$	11,4	17nA	100 $\mu s$	$5 \cdot 10^6$	1.1W	138mW
$^{40}Ar^{10+}$	11,4	30 $\mu A$ - 1,4mA	100 $\mu s$ - 1ms	$1,8 \cdot 10^9$ - $1 \cdot 10^{11}$	1,3kW -56,9kW	130mW - 11,3W
$^{64}Ni^{9+}$	5,5 u. 11,4	4,8 $\mu A$ - 17 $\mu A$	200 $\mu s$ - 5ms	$6,5 \cdot 10^8$ - $2,4 \cdot 10^{10}$	183W - 677W	37mW - 2,7W
$^{238}U^{28+}$	11,4	30 $\mu A$ - 2mA	75 $\mu s$ - 500 $\mu s$	$8 \cdot 10^8$ - $1 \cdot 10^{11}$	2,6kW -21,7kW	870mW - 4,3W



# Colours

	$\text{Al}_2\text{O}_3 : \text{Cr}$	$\text{Al}_2\text{O}_3$	Herasil	$\text{ZrO}_2$	$\text{ZrO}_2 : \text{Mg}$	BN
<b>Within the Pulse</b>						
<b>Afterglow</b>	the same colour $t_2: \sim 2\text{ms}$	the same colour $t_2 < 30\mu\text{s}$	 $t_2 < 30\mu\text{s}$	 $t_2 < 30\mu\text{s}$	the same colour $t_2 < 30\mu\text{s}$	 $t_2 < 30\mu\text{s}$

# Skewness and Kurtosis @ higher intensity



3 min. break

Same beam parameters for all samples

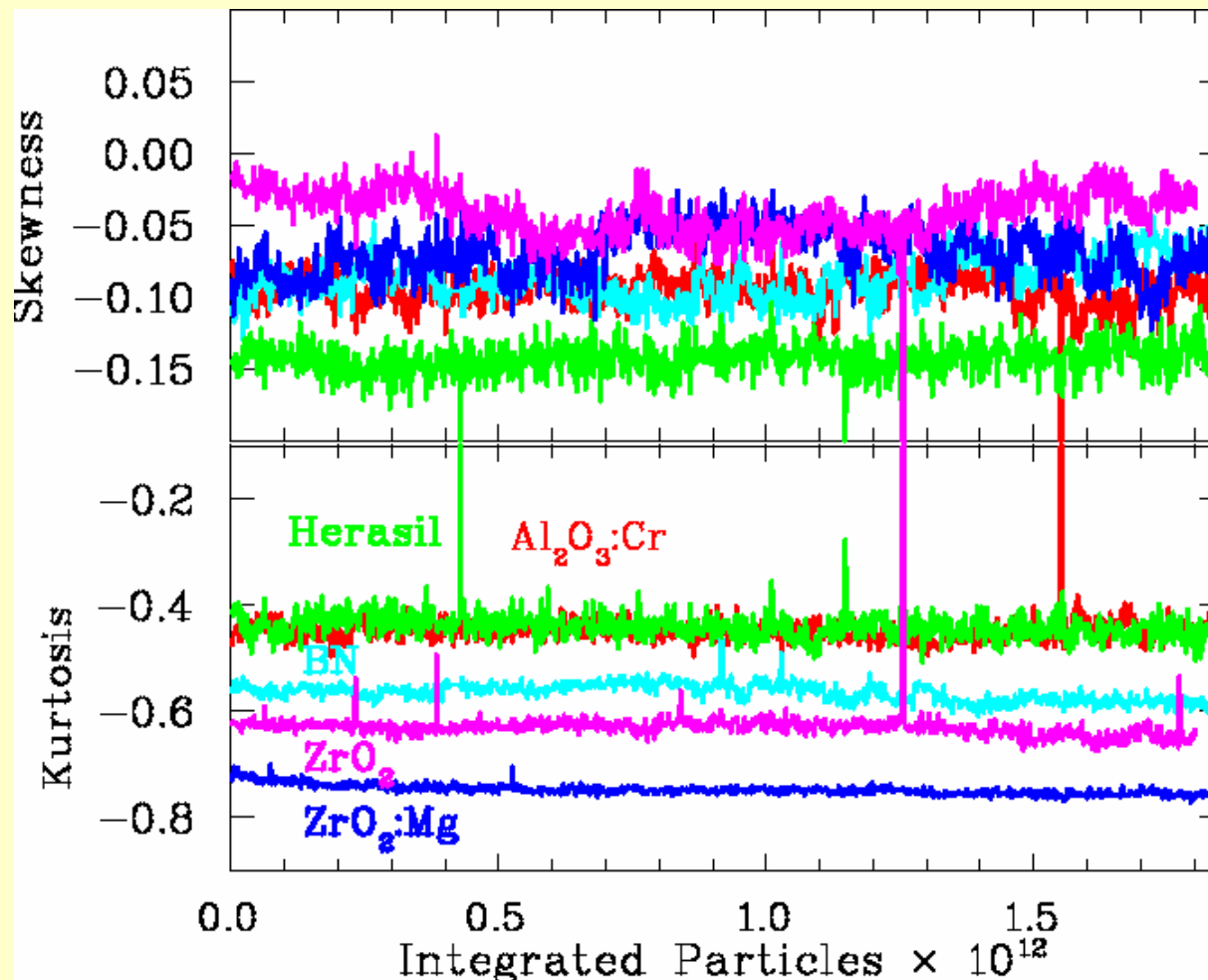
## Beam parameters:

$^{40}\text{Ar}^{10+}$

$2 \times 10^{10}$  Ions/Pulse in 100 $\mu\text{s}$ ,  
 $\sim 0,3\text{mA}$

2,6Hz

# Skewness and kurtosis @ low intensity



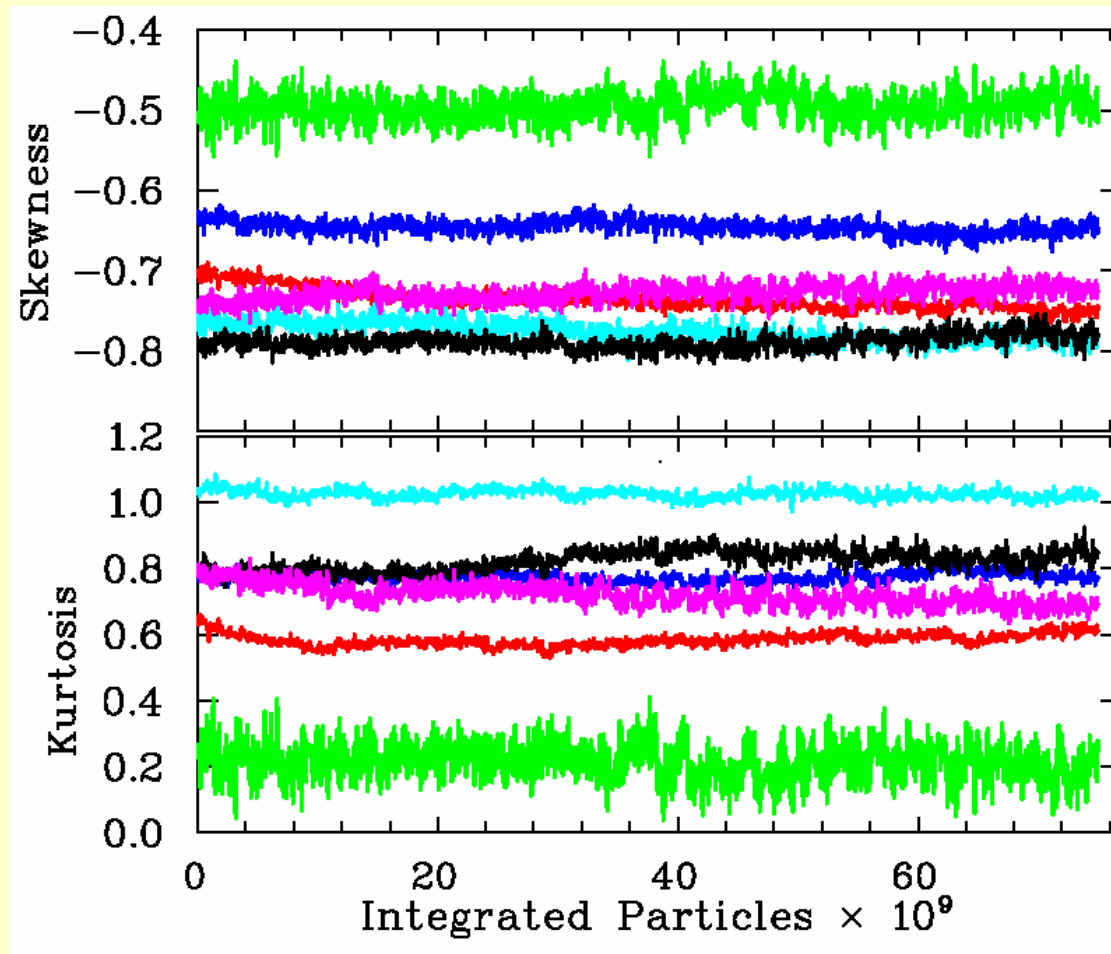
## Results:

- reproducible
- different light yield
- different width reading
- different beam shape

Average temperature: 47°C  
(backside of  $\text{ZrO}_2:\text{Mg}$ )

Beam parameters:  $^{40}\text{Ar}^{10+}$ ,  $2 \cdot 10^9$  Ions/Pulse in 100 $\mu\text{s}$ ,  $\sim 30\mu\text{A}$ , 1Hz, 1000 macro pulses

# Skewness and Kurtosis @ very low intensity



## Beam parameters:

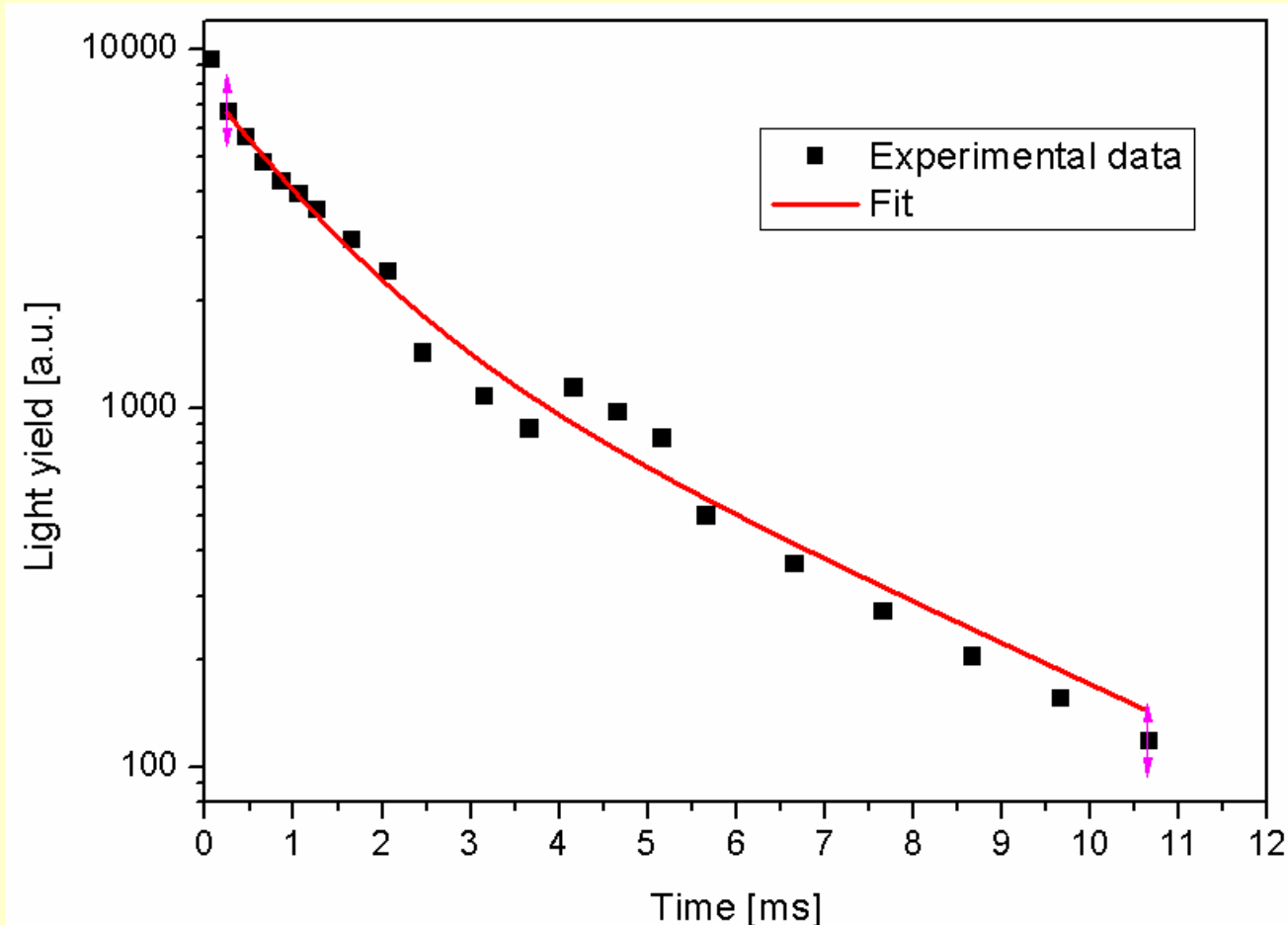
$^{12}\text{C}^{2+}$

$5 \cdot 10^6$  Ions/Pulse in 100 $\mu\text{s}$ ,  
~17nA

12,6Hz

Same beam parameters for all samples

# Decay time of $\text{Al}_2\text{O}_3:\text{Cr}$



$$y = a \cdot e^{(-t/t_1)} + b \cdot e^{(-t/t_2)}$$

$$t_1: 1.0919 \text{ ms}$$

$$t_2: 3.8263 \text{ ms}$$

there might be faster components

Other materials

$$t_2 < 30 \mu\text{s}$$